Air-Sea-Aerosol-Cloud Interactions

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LONG-TERM GOALS

The long-terms goals of our research are to understand and parameterize the physics of air-sea interaction and the Marine Atmospheric Boundary Layer (MABL) over a wide spectrum of wind speeds, sea state and cloud coverage.

OBJECTIVES

The main objective of this effort is to contribute to the understanding of air-sea-aerosol-cloud interactions under different wind and cloud coverage conditions. Our main focus is on obtaining direct measurements of the latent heat (water vapor), sensible heat and momentum fluxes near the surface, below clouds, in-clouds and at cloud top. Accurate measurements of these fluxes are needed for the parameterization of the surface forcing and the characterization of vertical transport in and near clouds.

APPROACH

Aircraft measurements of air-sea fluxes and boundary-layer structure were made during three different experiments: April 2008 off of Monterey Bay under mostly clear skies and with moderate to high winds conditions; July-August 2008 in the same area but in conditions of stratocumulus-toped MABL during POST (Physics Of Stratocumulus Top, a related NSF-funded project); and in October-November 2008 off of northern Chile during the VAMOS Ocean-Cloud-Atmosphere-Land Study – Regional Experiment (VOCALS-REx) also in conditions of stratocumulus-toped MABL. The NPS/CIRPAS Twin Otter research aircraft (Fig. 1), which we instrumented with turbulence instrumentation for previous ONR projects, was used.

WORK COMPLETED

For the sake of brevity we will focus in this section and the coming one mostly on VOCALS-REx.

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14. ABSTRACT

The long-terms goals of our research are to understand and parameterize the physics of air-sea interaction and the Marine Atmospheric Boundary Layer (MABL) over a wide spectrum of wind speeds, sea state and cloud coverage.

15. SUBJECT TERMS

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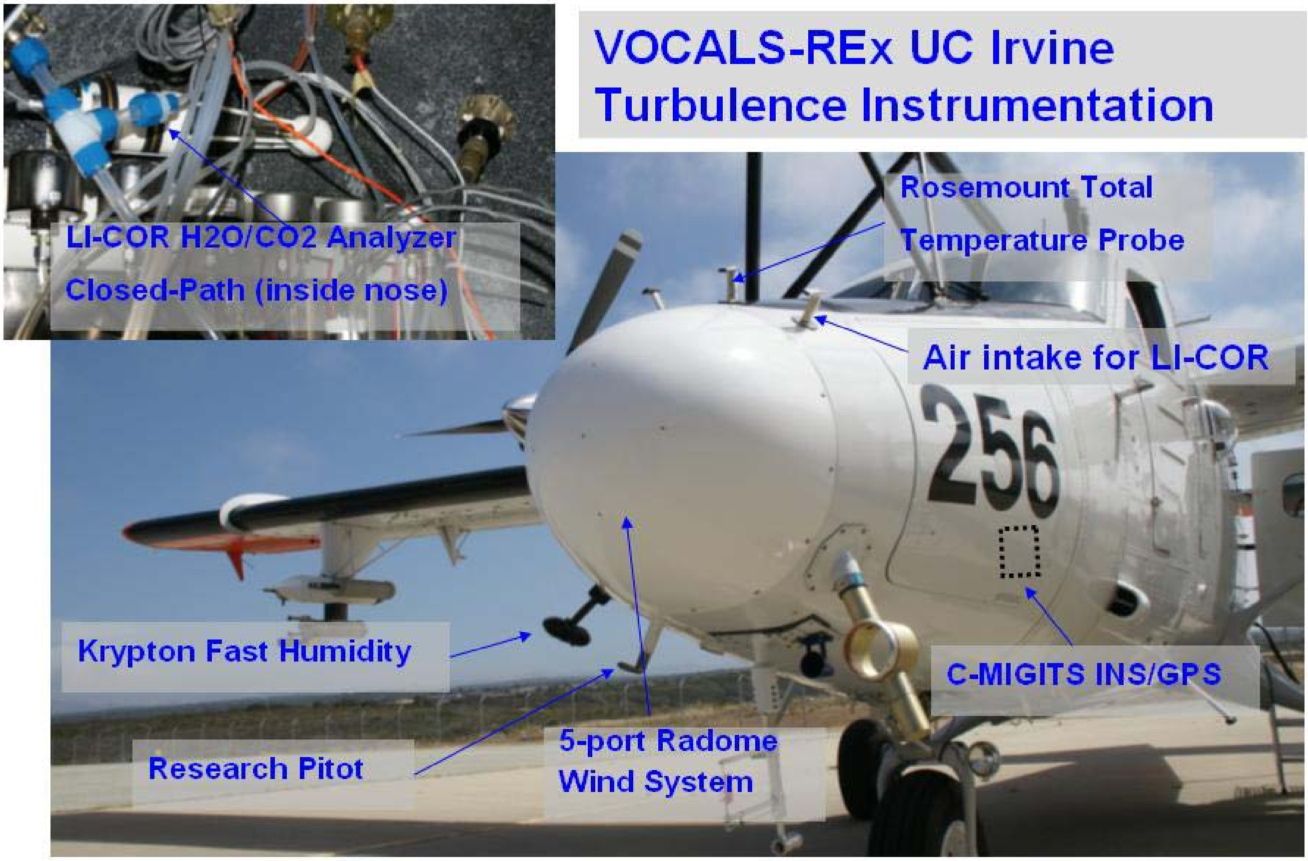

Figure 1: UCI Turbulence instrumentation on the CIRPAS Twin Otter in POST and VOCALS-REx field experiments in 2008. The insert shows the LI-COR 7500 used in closed-path mode just aft of the radome bulkhead.

Instrumentation

Prior to and in preparation for VOCALS-REx field phase, we made significant improvements to the UCI turbulence instrumentation package. We redesigned the pneumatic system for the radome wind gust probe to make sure ingested cloud liquid water is promptly trapped in special reservoirs and kept away from the pressure lines leading to the transducers. We used highly hydrophobic PFA tubing with an inner diameter wide enough to allow the droplets ingested through the radome pressure ports during in-clouds flights to bead and "slide" on the tubing inner walls (without bridging) to ultimately collect at the bottom of the vertically aligned water reservoirs. After a total of 36 flights (POST and VOCALS-REx combined) no wind data were lost due to water ingestion. The new system proved to be virtually maintenance free and does not require removal of the collected water between flights resulting in a much more efficient operation. In addition, wider tubing improves the frequency response of the pneumatic system as shown by Whitmore (2006).

We modified a Campbell Scientific KH2O absorption krypton hygrometer by mounting its source and detector tubes inside the housing of the obsolete AIR Lyman-alpha hygrometer. This fast responding sensor is our primary latent heat (water vapor) flux instrument. Due to lack of space around the nose ring for this experiment, we had to modify our open-path LI-COR H2O/CO2 gas analyzer to be used in closed-path mode inside the nose section. The ambient air was brought to it through an empty spare

non-deiced housing of a Rosemount 102E4AL total temperature probe (see Fig. 1). This housing is known to be very effective at inertially separating out hygrometeors and other debris from the sampled airstream. In this configuration, the LI-COR source and detector windows were kept free from liquid water ensuring good data quality even during prolonged cloud penetrations. The trade-off is a significantly slower response compared to that of the open-path configuration.

VOCALS-REx Field Experiment

We participated in VOCALS-REx that took place in the south eastern Pacific of off northern Chile from October 16 to November 13, 2008. Operating out of Iquique airport, the CIRPAS Twin Otter flew a total of 19 research flights with average flight duration of 5 hours. The same flight pattern as the one shown on Fig. 2 was repeated on each flight near 20°S, 72°W which was dubbed Point Alpha.

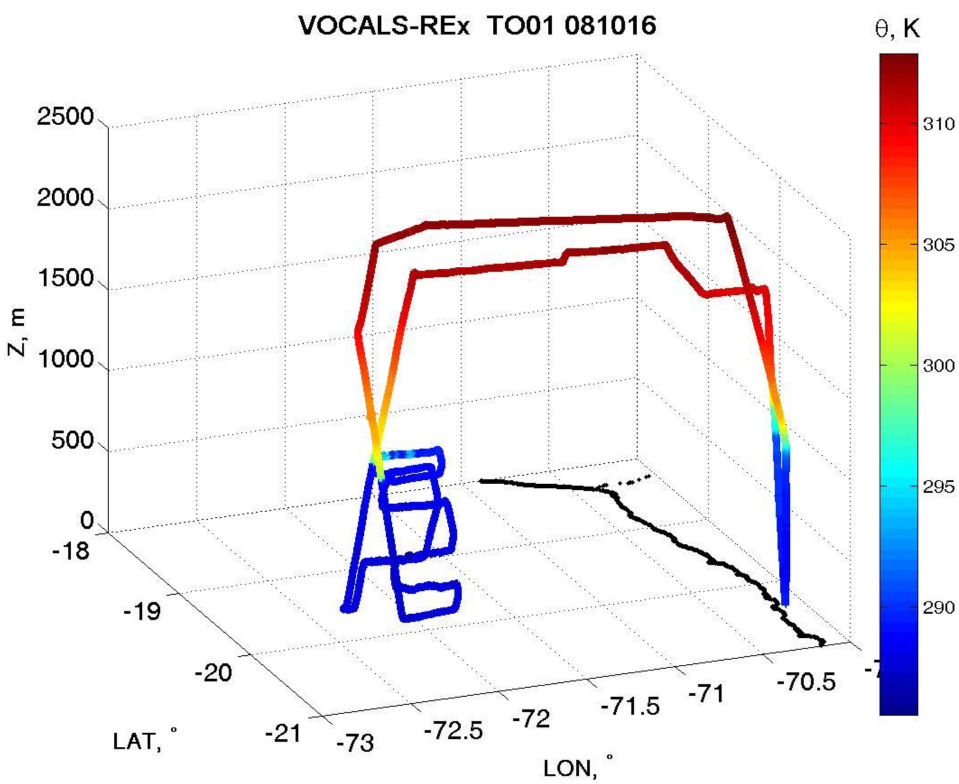

Figure 2: Typical Twin Otter flight pattern during VOCALS-REx around 20°S, 72°W (Point Alpha) off of the coast of northern Chile. Contours of potential temperature, θ, obtained from UCI's Rosemount sensor show a very sharp inversion with a roughly 13 K jump across the inversion.

As shown in the summary of Table 1, UCI turbulence instrumentation and data system performed well and did not experience any major failure. Once again, having redundant instruments for the measurements of fundamental parameters such as humidity paid off. The LI-COR 7500 data proved very valuable after the CIRPAS EdgeTech chilled mirror reference dewpointer experienced problems

in the last 7 flights. Even when the chilled mirror was operational, its signal oscillated during aircraft downward soundings when the humidity changed abruptly from very dry above the inversion to moist inside the MABL. This is due to overshooting of thermoelectric cooler and heat pump system control system that maintains the sensor mirror temperature at the dewpoint. The IR absorption-based LI-COR 7500 sensor did not experience such a problem and therefore was used as the reference humidity for all derived parameters. A sample of time series of calibrated absolute humidity obtained from the 3 sensors during 2 porpoises below and above cloud top is shown in Fig. 3. The path of the krypton hygrometer was set for optimum performance on the higher humidity range for the estimation of surface fluxes. As a result, its performance toward the low humidity range is not reliable which explains its clipped data at the nonphysical value of -0.6 g m^{-3} when it is out of range on the dry side. (Note also the large time lag inherent to the chilled mirror.)

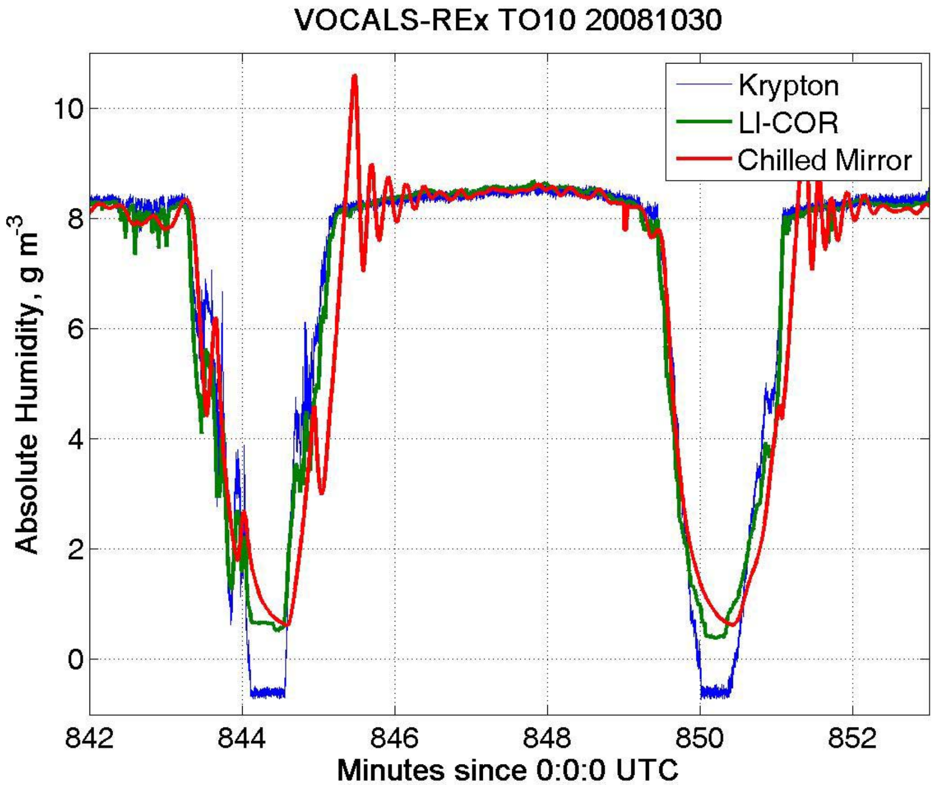

Figure 3: Absolute humidity from the krypton KH2O (blue), the LI-COR 7500 (green), and the EdgeTech chilled mirror (red) sensors during 2 porpoises below and above cloud top on October 30 2008. Note the oscillation of the chilled mirror signal when the humidity changes abruptly from dry to moist across the MABL inversion. The path of the krypton hygrometer was set for optimum performance in the higher humidity range for the estimation of surface fluxes this is why its signal is not reliable (clipped at the nonphysical value of -0.6 g m^{-3}) when it is out of range on the dry side.

Data from the UCI onboard system were processed immediately after each flight and first-look flight data and summary plots were made available to co-investigator by the time of the flight debriefing. The quick analysis proved helpful at detecting sensor problems and in making plans for the next flight.

***Table1: Status of instruments logged on UCI data system during VOCALS-REx (also available at** http://wave.eng.uci.edu/files/vocals/docs/VOCALS_Instruments_Status_7pt_uci_sortNN.JPG .)*

VOCALS-REx Oct16 - Nov13 2008		UTC Date	10/16	10/18	10/19	10/21	10/22	10/24	10/26	10/27	10/29	10/30	11/01	11/02	11/04	11/05	11/08	11/09	11/10	11/12	11/13
Contact Scientist	Instrument	Fltight	TO1	TO2	TO3	TO4	TO5	TO6	TO7	TO8	TO9	TO10	TO11	TO12	TO13	TO14	TO15	TO16	TO17	TO18	TO19
hjonsson@nps.edu	Rosemount Temperature																				
dkhelif@uci.edu	Rosemount Temperature (UCI)																				
dkhelif@uci.edu	LI-COR 7500 CO2 (UCI)																				
dkhelif@uci.edu	LI-COR 7500 Humidity (UCI)		xx																		
hjonsson@nps.edu	Edge-Tech Dewpoint																				
dkhelif@uci.edu	Mod. Krypton Hygrometer (UCI)																				
hjonsson@nps.edu	Radar Altimeter																				
hjonsson@nps.edu	Static Pressure																				
dkhelif@uci.edu	Radome Gust System (UCI) (x)																				
hjonsson@nps.edu	Heiman SST																				
dkhelif@uci.edu	Upward-looking IR Temp. (UCI)																				
dkhelif@uci.edu	C-MIGITS (UCI)																				
Legend																					
UCI	UCI and CIRPAS		Operational			Some data			No data			(x) Different processing			(xx) Clipped at 3.6 g/m^3						

Since VOCALS-Rex field phase ended, a more thorough processing of the data has been carried out. The wind calibrations were reassessed using flight data from special calibration maneuvers that were flown during the experiment. These consisted of pitching maneuvers to calibrate the angle of attack and the vertical component of the wind and yaw and reverse heading maneuvers to calibrate the angle of sideslip and the horizontal wind components. Details on the calibration techniques can be found in Khelif et al. (1999). The KH2O and LI-COR humidity data were calibrated against flight data from the chilled mirror when it was still operational.

So far, the data set went through 4 processing iterations and the latest version of the data set that was made available to co-Investigator is dated July 3, 2009. It can be obtained directly from our data server at this URL: http://wave.eng.uci.edu/files/vocals/datacuts/ and will also be available soon at the VOCALS data archive at his URL: http://data.eol.ucar.edu/master_list/?project=VOCALS. For each flight, a twelve-page summary showing flight tracks and time series plots from the UCI data set can be obtained at the VOCALS-Rex field catalog http://catalog.eol.ucar.edu/cgi-bin/vocals/research/index .

High-Wind Experiment

The data analysis of the April 2008 experiment off of Monterey Bay using the Twin Otter and the Controlled Towed Vehicle is well underway. Our cooperation with Dr. Larry Mahrt of Oregon State focused on developing and testing a new approach in estimating heat fluxes for cases with small air-surface temperature difference and modest surface temperature variability. The new method, which is based on multiresolution wavelet decomposition, was implemented on select cases of our data set. One of its main findings is the prediction that the horizontal heterogeneity of the SST increases the area-averaged heat flux for weakly unstable conditions, but decreases the area-averaged downward heat flux for weakly stable conditions. A manuscript (lead author L. Mahrt) describing this new technique and summarizing results of its implementation was submitted to the Journal of Geophysical Research.

We presented results obtained with the CTV at the 2009 AMS annual meeting. Two similar talks were also given at NCAR. In preparation for phase II of the CTV development we have been cooperation with Zivko and DMT. We installed the data acquisition software on DMT computer and gave their personnel a brief training on the system. We are also cooperating with Dave Emmit of Simpson Weather Associates, Inc. to combine the analysis of our data from the CTV and the data from the Twin Otter Doppler Wind LiDAR (TODWL) instrument to characterize the roll vortices that were observed near the surface when the two systems flew together. A manuscript describing the Controlled Towed Vehicle concept, its capabilities and results from its flight data is being prepared for publication in BAMS whose editor agreed on the suitability of such an article.

RESULTS

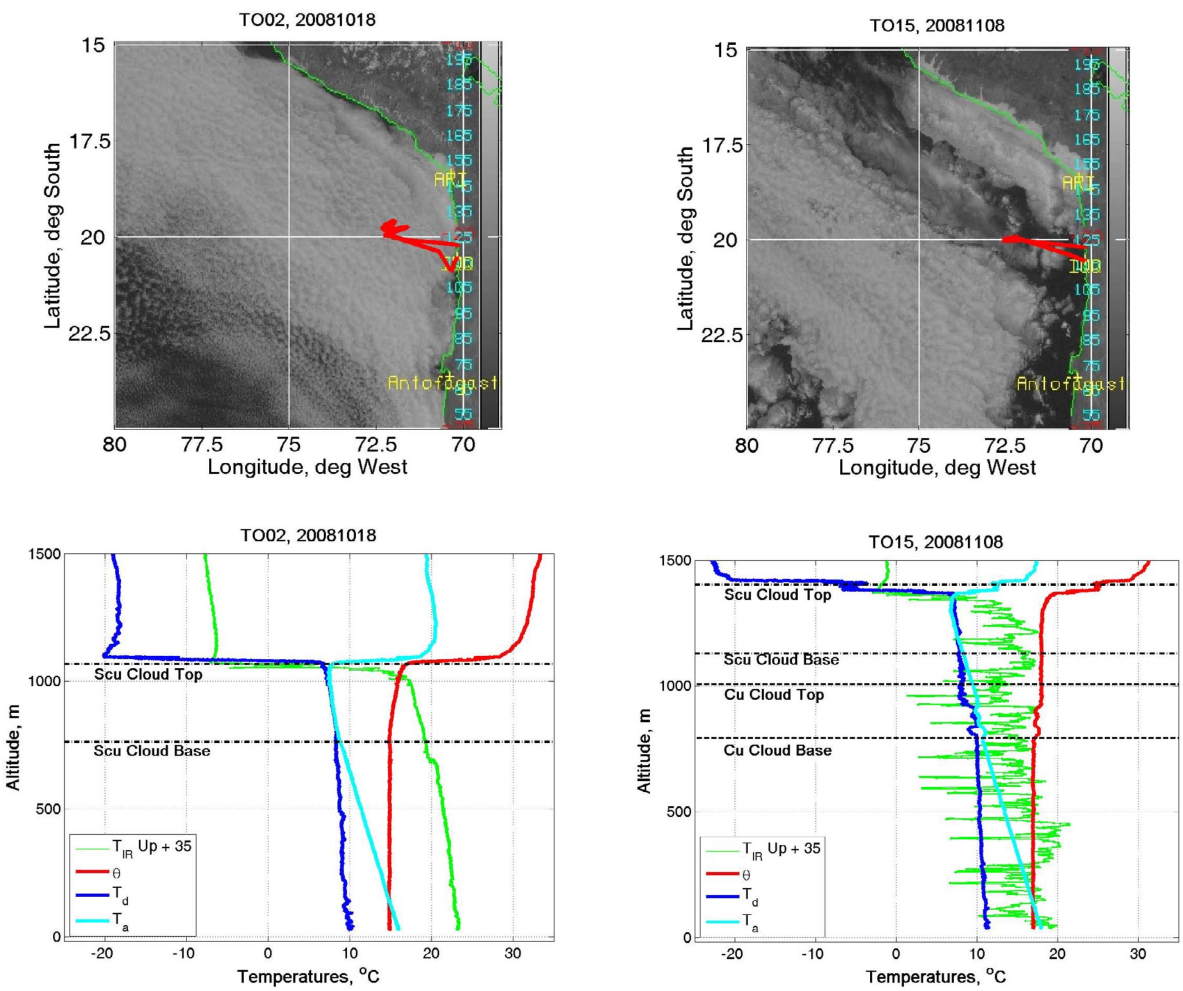

Figure 4: Top: Twin Otter Flight track (red) with cloud cover image from GOES-10 channel 1 (courtesy of NCAR/EOL) in the background for the flights of October 18 (left) and November 8 (right). Bottom: Corresponding profiles of dewpoint, T_d (blue) ambient temperature T_a (cyan), potential temperature, θ (red) and upward-looking IR temperature T_{IR} (green) obtained from aircraft soundings. (Observed Scu and Cu cloud base and top heights are indicated by the dashed lines).

The Twin Otter sampling strategy in VOCALS-REx consisting of flying the same flight pattern over the same location for the whole duration of the experiment had the advantage of providing us with a record of the temporal variability of the different measured parameters. An example of boundary layer vertical structure variability from a day with a solid stratocumulus (Scu) cloud deck (20081018) cover and a day with more open Scu clouds and some lower level patchy cumulus clouds layer (20081108) is shown in Fig. 4. Profiles of potential and dewpoint temperatures show the classic well mixed MABL for 20081018 with a very strong inversion and large jumps in potential temperature ($\Delta\theta$ ~16 °C) and dewpoint (ΔT_d ~10 °C). On 20081108 a lower cumulus (Cu) cloud layer was observed with a base at 793 m at and top at 1006 m as reported by the onboard observers. The fluctuations of θ and T_d within these heights and their respective mini-jumps of +2°C and -1°C as seen on their profiles seem to confirm the presence of this layer. This was a rare case where the Scu layer was decoupled from the surface. The profiles of the “sky” temperature from our upward-looking IR pyrometer are shown for a qualitative description of the cloud cover above the aircraft. The large negative deviations in this profile indicate the presence of holes (clear sky) in the clouds above the aircraft which is in stark contrast with the profile on the thicker and denser Scu layer on 20081018 where no such fluctuations were observed.

The photograph on Fig. 5 shows a view of stratocumulus cloud top during the Twin Otter inbound transect back to Iquique airport on October 18, 2008 (20081018) at about 63 km (34 nm) west of the coast. The sharp difference in cloud brightness between the thinner clouds closer to the coast (left) and the thicker and brighter clouds offshore (right) forms a clear demarcation line that roughly parallels the shore line. A closer look at the cloud structure shown on the 20081018 satellite picture of Fig. 4 seems to confirm that the clouds near the coast (especially directly south of the aircraft track where the camera was pointing) exhibit less brightness.

Figure 5: View of stratocumulus cloud top during inbound transect back to Iquique airport (direction of travel is from right to left, camera is pointing south). The sharp difference in cloud brightness between the thinner clouds closer to the coast (left) and the thicker and brighter clouds offshore (right) forms a clear demarcation line that parallels the shore line. The photograph was taken from CIRPAS Twin Otter about 63 km (34 nm) west of the coast on October 18, 2008 at 15:13 UTC (12:13 local daylight saving time).

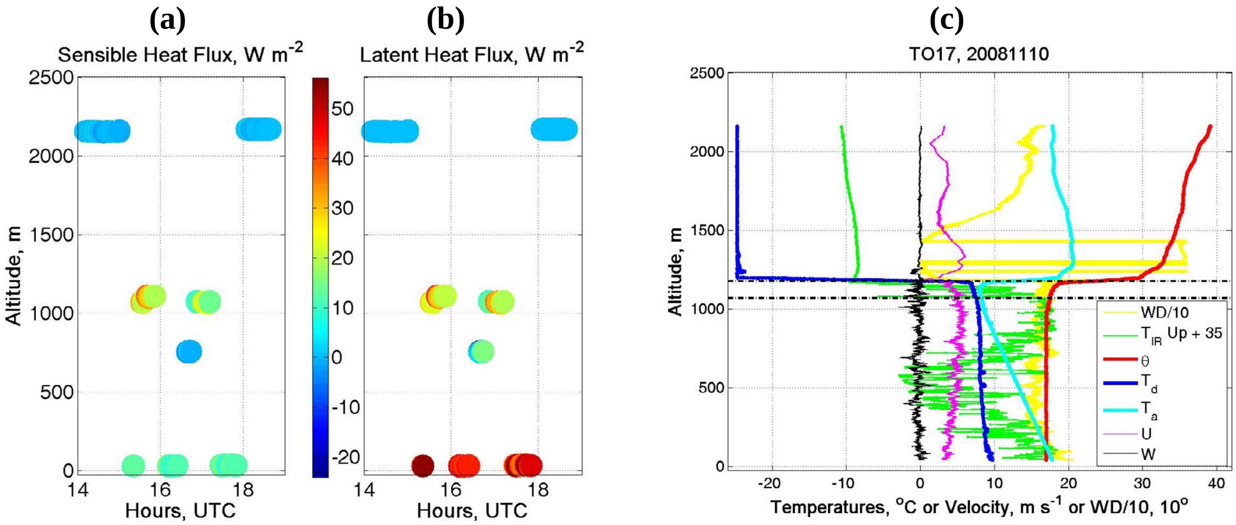

Figure 6: Contours of latent heat (a) and Sensible heat (b) eddy correlation flux estimates using a 3-minute sliding window technique on data from all level and straight legs of November 10, 2008 flight. Corresponding profiles of dewpoint, T_d (blue) ambient temperature T_a (cyan), potential temperature, θ (red), upward-looking IR temperature T_{IR} (green), 0.1×wind direction (yellow), wind speed (magenta) and vertical wind (black) obtained from aircraft sounding (c). (Observed Scu cloud base and top heights are indicated by the horizontal dashed lines).

Since November 10, 2008 flight was dedicated to rendezvous with the R/V R.H. Brown at point Alpha, instead of flying the typical pattern, many intercomparisons legs were flown very close to the ship including 7 (instead of the usual 2) low level (~ 30 m) runs . The Scu cloud deck was patchy and very thin with cloud base and top at 1067 m (3500') and 1174 m (3850') respectively. Although, this day was not representative for the typical conditions that prevailed during the experiment, the intercomparisons data are very useful for assessing errors in the different measurements systems. We will present sample flux results obtained from this flight. A 3-minute (~11 km distance) sliding window technique was used to estimate eddy correlation fluxes of momentum, τ, latent heat, Q_s, and sensible heat, Q_e, for all straight and level runs. Means (± one standard deviation) of the estimated surface fluxes from the 7 runs at 30 m were 12 ± 1.06 W m^{-2} for Q_s, 45 ± 3 W m^{-2} for Q_e and -0.032 ± 0 .016 Pa for τ.

Contours of the sensible and latent (Q_e) heats fluxes estimates displayed on an elevation versus time diagram are shown in Figs. 6a and 6b. Profiles plots similar to those of Fig. 4 (with added profiles of wind speed and direction and of the wind vertical component) are also shown on Fig. 6c to give context to the flux data. Of course, maximum values for both Q_s and Q_e are nearest the surface. On the below-cloud runs at ~750 m, Q_s is nearly zero and Q_e is very low. There is an increase in both fluxes at about 1075 m which was the nominal cloud base. However, the cloud layer being very thin and patchy, the 10 °C warmer and dryer air is only about few tens of meters above the actual levels of these flux runs. So it is possible that the heat transfer is augmented by enhanced mixing due entrained air from above. This is plausible given the observed wind shear associated with the jet just above cloud top (the wind backed abruptly from ~165° to ~0°). Finally data from the ~2200 m transect legs flown in the quiescent air both fluxes are close to zero as there is no turbulence.

The surface sensible heat flux is examined further in Fig. 7 where the top panel shows Q_s time series from all seven 30-m runs on the right axis together with the surface-air difference in potential temperature on the left axis. The lower panel is a magnified version of the same plot showing in more detail data from the second run from the left which happened to be the longest run. The variations of Q_s and θ_s-θ_s appear to track each other closely except perhaps for the two last runs. This suggests that bulk flux calculations would in general agree with these eddy correlation estimates. The mean of the sensible heat bulk transfer coefficient (C_H) estimated from the 7 runs is 1. 31×10^{-3} (standard deviation of 0.21×10^{-3}) appear to be relatively higher than the expected ~1.0×10^{-3} value. This may be due to the eddy correlation estimates of the sensible heat being too high or to biases in the measured mean wind speed (too low), ambient temperature (too high) and SST (too low). These possibilities are being investigated and the discrepancy should be resolved once the ongoing analysis of the intercomparisons with the R/V R.H. Brown is completed.

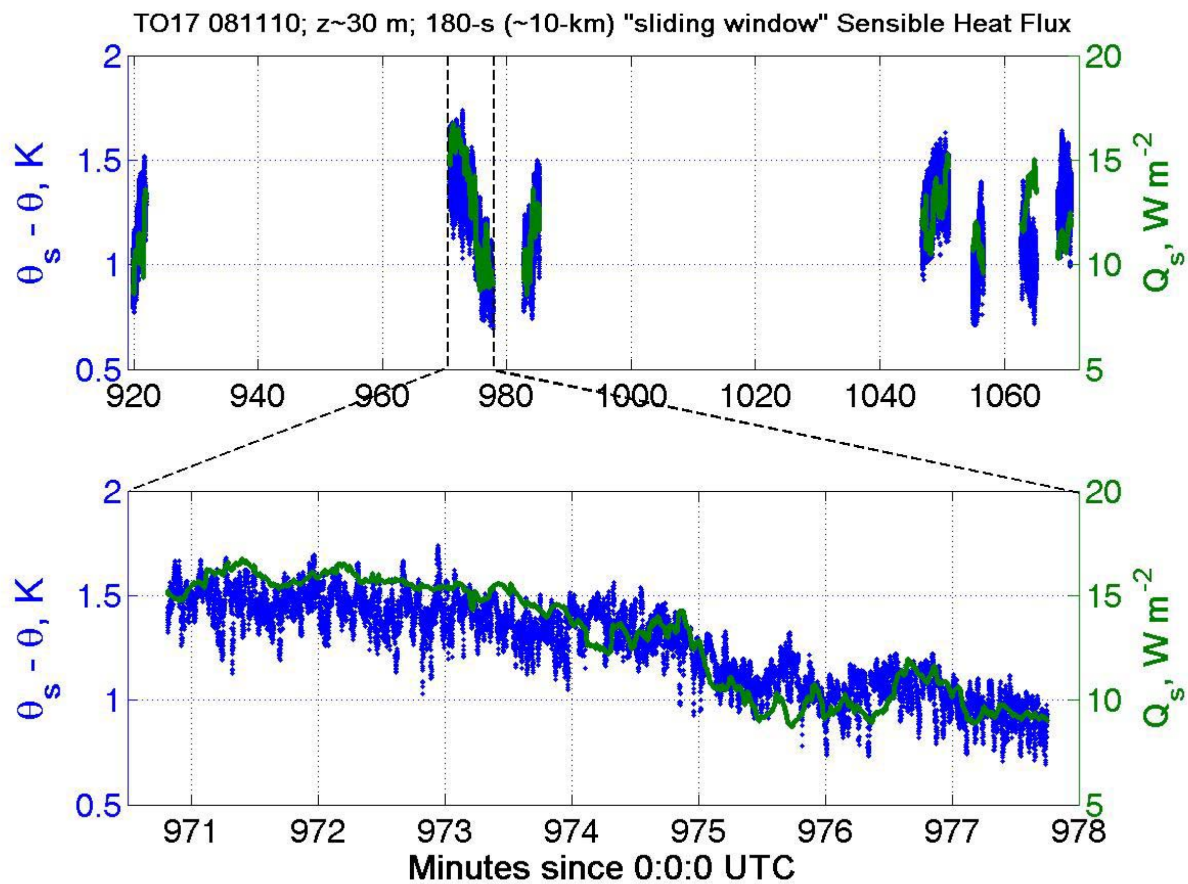

Figure 7: Time series of surface eddy correlation sensible heat flux estimates using a 3-minute sliding window technique (green, left axis) and of potential temperatures difference between the surface and the air (blue, right axis) versus elapsed in minutes since 0:0:0 on November 10, 2008. (Data are from 7 Twin Otter level and straight runs at ~ 30 m)

IMPACT/APPLICATIONS

The modification of the Twin Otter radome wind system to prevent ingested water during cloud flights from obstructing the pressure lines between the pressure port and the sensing transducer was successful. This technique can be implemented on other research aircraft especially if the research projects focuses on cloud work or heavy rain bands such as the ones encountered in tropical storms and hurricanes. The modified krypton hygrometer is a good alternative to the obsolete AIR Lyman-alpha for fast-response humidity measurements from research aircraft.

RELATED PROJECT

POST: The Physics of the Stratocumulus Top experiment (funded by NSF) was conducted off the cost of Monterey, CA from July 16 through August 15, 2008. We completed 17 flights with Sc coverage varying from thick and very compact to thin and broken. Our data analysis will focus on case studies comparisons between POST and VOCALS-REx to determine the similarities and differences between the Scu topped MABLs in the two studied regions.

CTV: The Controlled Towed Vehicle has been developed in collaboration with Zivko Aeronautics Inc. and CIRPAS. The CTV is a unique platform for the measurement of air-sea fluxes and other variables at heights as low as 10 m over the ocean. The reasonable meteorological and eddy correlation fluxes results we obtained from the CTV data established that the concept works. The demonstrated viability of the CTV seems to be generating increased interest from the research community based feedback received after the numerous formal and informal presentations we gave. We are involved in the process of its phase II development with the set objectives of (i) improving the CTV height keeping control and to extend it beyond the range of the radar altimeter; (ii) adding to the instrumentation (aerosol, wave height measurements etc …), and (iii) integrating it onto a larger research aircraft such as the NOAA WP-3Ds or the NSF/NCAR C130Q aircraft. When these objectives are successfully achieved, the CTV should greatly enhance the capabilities of airborne research especially when combined with the longer range and higher endurance of larger aircraft. It will make measurements near the air-sea surface possible even in very high winds (up to hurricane force) while keeping the tow aircraft at a safe height above the inhospitable environment of sea spray and spume.

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